OPTICAL MATERIALS

Variety pays off for nanotubes

Carbon nanotubes are usually produced in samples that contain a mixture of different diameters and electronic properties; this is a problem for applications in nanoelectronics but is advantageous when generating ultrashort laser pulses.

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The global communications infrastructure relies on optical fibre lasers and other photonics components. As traffic on these networks continues to increase by a stunning 40% per year, hardware companies are under pressure to reduce costs. There is thus a need for new, low-cost optical technologies that deliver high performance and can be manufactured in an environmentally friendly manner. On page 738, Andrea Ferrari of Cambridge University and co-workers[1] demonstrate that carbon nanotubes, incorporated into a transparent polymer matrix, can be used as a practical and efficient photonic material for the generation of ultrashort pulses at communications wavelengths by fibre lasers.

Pulsed laser sources are deployed in a wide variety of applications ranging from basic scientific research and metrology to eye surgery and materials processing. Regardless of wavelength, the majority of laser systems producing pulses with durations of picoseconds and shorter use a mode-locker — a nonlinear optical element called a saturable absorber — that turns a continuous wave output into a train of ultrashort pulses. The main requirements for the nonlinear materials used in mode-lockers are a fast response time, strong nonlinearity, broad wavelength range, low optical loss, high power handling, low power consumption, low cost and ease of integration into an optical system.

Currently, multiple-quantum-well semiconductor heterostructures are regularly used as saturable absorbers. However, the techniques used to fabricate and package these structures are expensive and environmentally unfriendly (because they involve toxic materials such as arsenic), even though they are well-established. Moreover, each design tends to be application-specific, covering a relatively narrow wavelength range (about 100 nm).

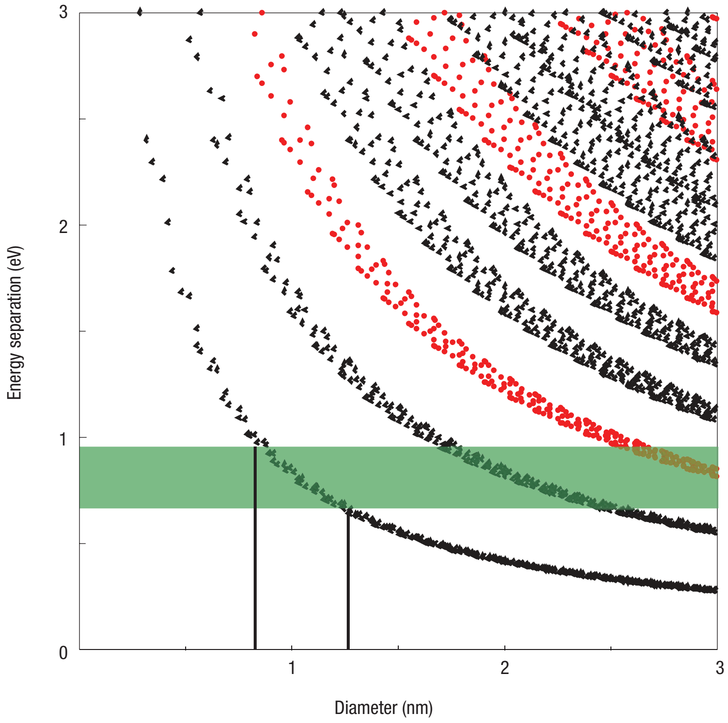

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Figure 1 A carbon nanotube can be defined by two numbers that determine its diameter and other properties. Each dot in this Kataura plot[12] corresponds to a different pair of numbers, with black and red dots representing semiconducting and metallic nanotubes, respectively. For semiconducting nanotubes the energy separation (vertical axis) is the bandgap, which is inversely proportional to the diameter (horizontal axis). The green region corresponds to the telecommunications window (1,300–1,600 nm): semiconducting nanotubes with diameters between 0.8 and 1.3 nm have bandgaps in this window and could therefore be used in saturable absorbers for telecoms applications.

Nanotube composites have the potential to overcome all of these shortcomings. First, they function well as nonlinear optical elements. Semiconducting nanotubes can absorb photons with energies that are close to the value of their bandgap (the difference in energy between their conduction and valence bands), creating electron–hole pairs in the process. However, this causes the conduction and valence bands in the nanotube to fill up with electrons and holes, respectively, causing the absorption to saturate. Under saturation, or 'bleaching', an increase in the laser power will not result in increased absorption by the sample. It is this nonlinear behaviour that makes nanotubes suitable for ultrashort pulse generation. Furthermore, the window of interest for optical communications is between 1,300 and 1,600 nm, which corresponds to nanotubes with diameters of between 0.8 and 1.3 nm (Ref. 2) (Fig. 1). Nanotubes with diameters and bandgaps in this range are readily available and have already been shown to display useful nonlinear properties[3–5], including saturable absorption for mode-locking applications.

Another feature of nanotubes is that it is difficult to make samples with a narrow absorption spectrum, or to make only semiconducting or metallic nanotubes. This is usually a problem for nanoelectronic applications, and intense efforts to sort nanotubes according to their diameters and/or electronic properties are ongoing[6–8]. For ultrafast optics, however, these characteristics can be an advantage. The presence of metallic tubes increases relaxation speeds, another important property for ultrafast devices. If the excited electron–hole pairs relax back to their ground state quickly, the system rapidly returns to the linear absorption regime and a new saturation–relaxation cycle can begin. This process is naturally very fast in semiconducting nanotubes, and the presence of metallic nanotubes makes it even faster. That is because electrons and holes can tunnel from the semiconducting nanotubes to their metallic counterparts. In addition, the wide absorption spectrum allows for a wide tunability.

Ferrari and co-workers have put all of these characteristics to use. Using nanotubes dispersed in a polycarbonate matrix, they built a fibre laser that generates ultrashort (2.4 ps) pulses, with a wavelength that can be tuned between 1,518 and 1,558 nm. They suggest that wider tunability should be possible with a wider distribution of nanotube diameters. In separate work, Fabian Rotermund of Ajou University and co-workers have demonstrated that nanotube-based saturable absorbers for ultrashort pulse generation can be easily fabricated through both spinning and spraying techniques[9]. The combination of ease of fabrication and wide tunability shows the potential that nanotubes hold for nonlinear optics.

Indeed, the potential applications of polymer-dispersed nanotubes[10] extend far beyond mode-lockers. Nanotube–polymer composites can be made with a low-cost, room-temperature fabrication process, and they are easily manipulated by a variety of methods — such as embossing, stamping, sawing and wet- or dry-etching — which makes them an ideal platform for integrating photonic devices. Moreover, polymers can be synthesized with well-defined optical characteristics such as transparency in selective wavelength ranges, variable refractive indexes and low birefringence. These properties mean that nanotube–polymer composites could prove useful in a large number of applications in optics including flexible transparent conductors, charge-transport layers in light-emitting diodes, displays and photovoltaic cells, nonlinear optical switches, optical limiters and, possibly, new light sources[11]**.** In addition, they might also be used in biomedical instruments, chemical analysis, time-resolved spectroscopy, environmental sensing, microscopy and surgery.

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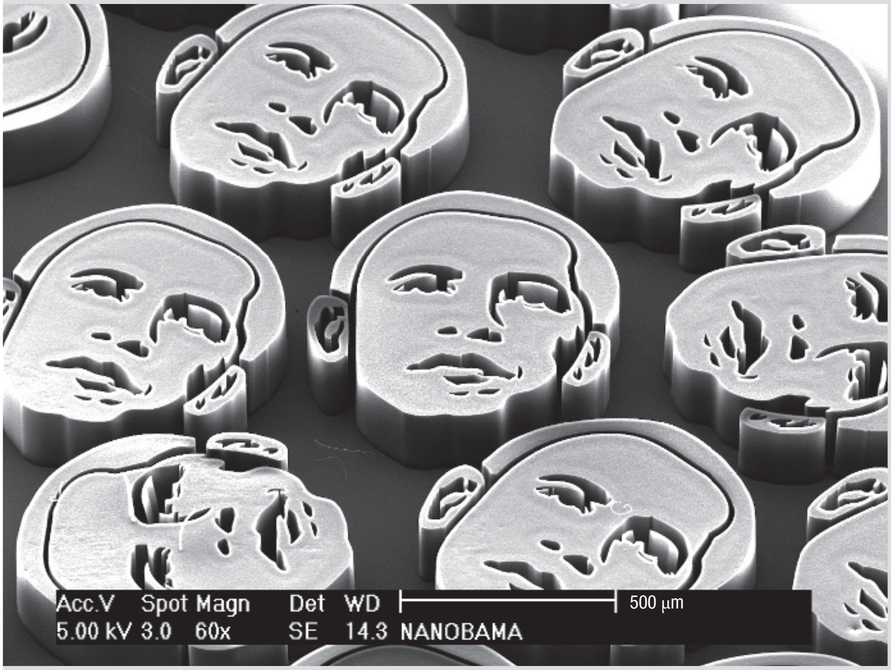
NANOSTRUCTURES

Welcome to nanobama



JOHN HART/SAMEH TAWFICK/MICHAEL DE VOLDER/ WILL WALKER/WWW.NANOBLISS.COM

The giant granite sculptures of George Washington — the first president of the United States — and three of his successors at Mount Rushmore are some of the most famous images in the world. It took more than 14 years and some 400 workers to complete the 18-metre-high sculptures. Now Barack Obama — who will become the 44th president of the US — has been immortalized in carbon nanotubes barely a week after he was elected. John Hart of the University of Michigan and co-workers grew the nanotubes on a silicon wafer patterned with an iron catalyst to produce a variety of images (www.nanobama.com). In the electron micrograph shown here, each face contains about 150 million nanotubes. “We had no political message in mind,” says Hart, “other than to draw attention to the science and applications of nanostructures in the hope that people who wouldn’t otherwise read about nanotechnology may want to learn a bit more.”

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